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ABSTRACT

Traditional user interfaces such as WIMP (Window, Icon, Menu, Pointer) interfaces are widespread in schools and have been proven to be useful in many scenarios. Unfortunately, they have shown to be unfit in the case of collaborative learning. Indeed, this type of activity at school is mainly based on physical interactions with paper, objects and often happened around a table. However, technologies have evolved and interfaces that support rich 3D interactions are becoming more and more used by HCI researchers to go beyond the paradigm of screens, mice and keyboards. In this paper, we present doctoral research that proposes to overcome current usages in classrooms by exploiting the advantages of hybrid environments for collaborative learning. We based these interfaces on tangible user interactions and spatial augmented reality that support collaboration and physical manipulation of digital content in an unique hybrid space. Interactions will be designed by applying instructional design principles as well as learning theories from cognitive science and education science. This paper also presents first results of our ongoing work as well as future directions that will involve focus groups with practitioners and experiments in classrooms.

KEYWORDS

Mixed-Reality, Tangible Interaction, Spatial Augmented Reality, Instructional Design, Collaborative Learning

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1 INTRODUCTION

Since at least two decades, schools have introduced computers in classrooms to allow children to discover the digital world and learn how to use it. It was at the beginning a way to get use to these new interfaces instead of using them as pedagogical tools. The shift started about fifteen years ago while school books began to be sold with compact discs, providing the first digital resources for teachers and pupils. More recently, schools started to use tablets instead of traditional computers that propose a similar access to digital information, but in a more convenient way.

Nonetheless, we still use a single kind of device, equipped with (touch) screens, mice and keyboards and all the current computers rely on the well-know WIMP (Windows, Icon, Menu, Pointer) paradigm. "This generic interface provides us a window, through which we need to jump in order to reach the digital realm." [19]. Such interfaces have shown great benefits for web browsing, text editing, and so on. However, they are limited as soon as collaborative interactions or hands-on activities are required [13]. This is particularly true for learning applications [20].

During this PhD, we will focus on the design of interfaces that go beyond the traditional and wide WIMP (Window, Icon, Menu, Pointer) paradigm and explore approaches that favor rich 3D interactions, giving more importance to physical manipulations. We want to enable children to collaborate around a unique space by anchoring the collaborative learning experience with the digital, in the real world, allowing the computer to disappear.

From these objectives, two mains research questions appear :

- What are the requirements to build a space where digital and physical world coexist ?

- How this kind of hybrid space can support the learning in collaboration ?

1.1 Learning, in collaboration

Learning is a cognitive process that permit to acquire new knowledge or modify existing knowledge. It can be impacted by numerous factors as psychological or social. As stated by S. Dehaene in his class at *Le Collège de France*, the field of cognitive neuroscience has identified at least three factors that can tune the speed and learning facility at school.

1) Attention : The fact that children are focused on the right things to learn without being disturbed by other factors.

2) Active learning or active engagement (intrinsic motivation): The fact that children are engaged in their activity. For that, we have to maximize curiosity and active prediction.

3) Feedbacks, error signals and rewards (extrinsic motivation). The comparison between the prediction and the outcome is a key role in the learning process.

Additionally to those factors, the Instructional Design (ID) approach aims to distinguish the impact of different aspects that influence the cognitive load required during a learning activity [22]. The first one is the content to learn, called the intrinsic cognitive load. The extrinsic load refers to the manner in which information is presented to a learner. Finally, the germane load is the way information is processed and automated.

One of our objectives in this thesis will be to reduce extrinsic cognitive load during manipulation on our interfaces, to favor collaborative learning (CL).

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CL is a situation of collaboration where the common goal is to learn or attempt to learn something together [3]. All the mechanisms dedicated to collaboration such as negotiation, sharing of meanings, coordination, are then applied to the purpose of learning. CL is often used for learning complex notions that are difficult to learn alone and where the cognition of pairs allow to reduce the amount of working memory needed to complete the task.

1.2 The e-TAC project

This PhD is part of an interdisciplinary project called e-TAC that aims to design tangible and augmented collaborative learning environments for children at school. e-TAC works also towards promoting social relationship, knowledge sharing and conceptualization of new concepts. This project gathers together researchers in Human-Computer Interaction (HCI), education science and ID. Furthermore the goal is not only to design that kind of interfaces but also to create adapted pedagogical content by working with practitioners like teachers, inspectors of the national French education as well as pupils.

2 MIXING THE REALITY WITH THE DIGITAL

During this PhD project, we take sides to base our interfaces on Tangible User Interface (TUI) and Spatial Augmented Reality (SAR).

2.1 Manipulating the digital with physical interaction

TUIs are interfaces in which physical objects and their surfaces are enhanced through embedded computation. Thus, the physical world becomes an interface that can connect objects and the environment with the digital world [18]. Since TUIs are becoming in HCI a common way to create interfaces that go beyond the use of screens, keyboards and mice. TUIs originally come from the special issue "Back to the Real World" (1993) [24], which argued that computers and virtual reality take humans away from their "natural environment". Later, Ishii et al [9], presented a more comprehensive approach with *Tangible Bits* and with first prototypes like Urp [23].

2.2 Bringing the digital onto the real world

Exposing digital information onto the real world without using screens is relatively new for HCI. To create such augmentation, we make use of SAR, which is a specific kind of augmented reality (AR) that proposes to project onto the real world digital contents [15] instead of see-through devices as usually done in AR. The *digital desk* [24] is one of the first interfaces to take advantage of the projection to augment the environment. The main advantage of using SAR is the possibility to augment different surfaces like horizontal surfaces (i.e. [7, 12]) and objects surfaces that can be moved inside the projector's frustum.

2.3 Benefits of mixed-reality

Mixed-reality based on projection and tangible interactions comes with some benefits, in particular for education purposes. First of all, Jacob [10] proposed the notion of reality-based interaction (RBI) as a unifying framework that ties together a large subset of these interaction styles including augmented reality and tangible interaction. Jacob et al, identified four types of interaction that all styles have in common: Naïve Physics, Body Awareness and skills, Environment Awareness and Social Awareness.

Researchers suggest that physical interactions (Naïve physics) could reduce the requirement of abstraction and ease the learning, thanks to the more *intuitive* way to interact with the interface and its content [13]. Tangible components of MR interfaces could also promote active learning and hands-on engagement [13, 25]. This allows the learning of abstract concepts with concrete representations [6] and in particular thanks to the 3D representations of manipulated elements. MR interfaces allow users to try more solutions with physical manipulation and allow them to spend more time exploring when performing problem solving tasks [4, 16].

Tangible interactions take place in the external (physical, real) world that acts as a support for our cognition by loading and storing information as described by the extended cognition [21].

In addition of the external world, other people or artefacts can also share and store information regarding an activity (i.e. problem-solving), as stated by the distributed cognition theory [14]. MR based on projection can also support collaboration by displaying and spatializing digital contents onto the real world (Environment Awareness). Those contents become manipulable by multiple users, a negotiation space favoring collaboration through speech and mutual gazes (Social Awareness) [3, 17].

2.4 Tangible and augmented interfaces for education

Among the previous works that have been done on MR for education, we can cite Hobit for *Hybrid Optical Bench for Innovative Teaching* [7]. It is an augmented tabletop that proposes to enhance the learning of optics with an augmented tabletop that reproduces practicals at university. This interface benefits from both physical manipulation and pedagogical supports that are embedded within the experimentation.

The Tinker Lamp is an augmented tabletop interface for training logistics assistants [11, 26]. This system uses paper sheets as input. Papers are also used as output surface in order to fit the projection size. It allows students to create and shape warehouse with 3D shelves.

Still for the purpose of learning new concepts, Do-lenh et al. , [5], built an application for The Tinker Lamp, allowing users to build concept maps on a synaptic transmission. Learners could for instance create links between two concepts by placing pieces of paper side by side and delete the same link by placing two fingers onto the link.

3 FIRST RESULTS

The following section summarizes our initial results presented in [8]. (See the paper for more details).

In this work, we have explored an approach based on the hybridization of physical and digital content for mind-mapping activities at schools. We have designed a MR interface called Reality-Map.

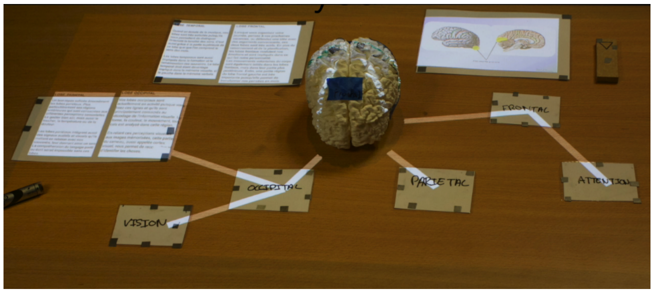

Figure 1: Reality-Map is dedicated to mind-mapping activities by combining real and digital content an unique hybrid space.

3.1 Introduction

Mind-mapping is a technique for fast idea generation and is often used in planning, critical thinking, studying, note taking and problem solving. Buzan et al[2], showed that mind-mapping make ease categorization and learning.

With Reality-Map, users can spatially organize the studied content by manipulating augmented papers and plastic-coated cards allowing users to write with whiteboard markers on cards and embed them within the mind map (see Figure 1). Users can also create (draw) and remove links with a specific tracked pen. These links are highlighted straight lines projected between two objects.

3.2 Implementation

We implemented Reality-Map using a projector-camera (procam) system to display digital information on the table and tracked which and where were pieces of paper and objects on the table. We calibrated the procam system using a manual technic (see Appendix A.2.2 Manual techniques [19]). The hardware side consists of an Optitrack's Trio composed of three infrared cameras and a video-projector placed above the user for the augmentation of the horizontal surface. The software side is composed of Optitrack Motive, that handles input from Optitrack Trio and then send information via UDP to the second software, Unity 3D. Unity3D is used to create the graphical UI (documents and links). The 3D calibration allowed to project the digital information to the right placed, creating the illusion that digital contents are attached to their corresponded objects.

3.3 Pilot study

We carried out a pilot study to evaluate Reality-Map by comparing it with a WIMP interface called Draw.io. The assumption of this study was that mixed-reality interfaces based on tangible interactions and projection are not only suitable for providing reality-based interactions but may also favor the building of knowledge for learning complex notions. For this pilot-study, we chose basic brain functions as the targeted knowledge. Our hypotheses were :

H1: Learning scores will be better in the tangible group compared to control group.

H2: Participants will better recall knowledge learned during the experiment after 5 days with Reality-Map.

3.4 Experimental design

For this between-subjects experiment, we randomly split participants in two groups. A "Control group" had to use the WIMP interface to create the mind-map and the "Tangible group", which had to do the same task but with Reality-map.

The procedure was conducted as follows. First, participants answered pretest regarding their knowledge about the brain. Then, depending on the group, participants used the WIMP software Draw.io or Reality-Map. During 10 min, participants discovered and manipulated documents about brain areas. Then, the task consisted in the creation of a mind-map on the theme: "Brain structures and their cognitive processes". This task had to be done in 10 min. Finally, participants had to fill a post-test questionnaire regarding what they learned during the session. Five days after the experiment, participants were invited to answer a second post-test questionnaires.

3.5 Results

Analyses (a two-way mixed ANOVA) showed that participants scored significantly higher in the post-test that they did in the pretest,($F=5{,}256$; $p<.05$) for the two groups, however the tangible group was significantly better than the control group.

4 CURRENT WORK

From the literature and previous experiments realized during this PhD, we started to develop a second major prototype that will be deployed in a pilot classroom. The current interface is supporting the same features as Reality-Map and aims to go beyond. Most of the work done yet concerns the technology that supports the projection. Indeed, SAR compels to calibrate the 3D environment by getting intrinsic (i.e. lens distortion, size, optical center), extrinsic (position) parameters of each optical element in order to project digital media at the right position and without distortion. Reality-Map used Optitrack camera and software, which are very precise but expensive and thence cannot be deployed in classrooms. In parallel to the creation of this hybrid environment, we are also designing TUIs that will provide to users a way of manipulating digital content.

Interaction techniques developed for this interface will respect ID principles and learning theories that have been presented previously. We also want to promote the curiosity and exploration possibilities of children by not constraining them too much and provide an environment that let them discover [1]. Finally, the interface will be built to support collaborative interactions. Some actions will be allowed only when there is more than one user around the table. On the contrary, other actions will be permitted only once at a time to create a bottleneck that will force negotiation and argumentation.

5 FUTURE WORK

5.1 Focus group and elicitation sessions

With the prototype that is currently under development, we will enter in a second phase where future users will be directly involved in the process of development. Two focus groups will be organized. The first one will be held with teachers and practitioners from the

French national education. This focus group will let them see and give feedback on the first concrete MR prototype.

A second series of focus groups will be organized with pupils. The goal of these sessions will be to elicit feedback on how they perceive the interface and the developed interaction techniques. Furthermore, letting children interact spontaneously with an interface without giving them instructions can be really interesting by observing how they interact with the interface. Such observations can highlight some aspects of our interface that we did not through about.

For instance, during the first elicitation session, some children try by themselves to zoom on the picture that was projected on the table. Several focus groups will be regularly organized until a consensus between researchers and practitioners is found.

Finally, we will also focus on the usability and acceptability of our interfaces, which are the main current approaches used in HCI to evaluate interfaces.

5.2 Evaluation

We will formally evaluate interfaces in both control and ecological environment. Alongside of general questions of usability and acceptability and more generally, the user experience, we would like to answer these following questions:

1. Will the learning performances be the same with a mixed-reality interface than with robust interactive tabletops based on multi-touch screen ?

2. Are mixed-reality interface good for all types of content ?

3. Do we have the same representations of the content we manipulate on post-WIMP interfaces compared to more traditional WIMP interfaces?

We choose these questions based on the literature and previous experiences with MR interface for education. Indeed, for the first question, researchers point out the fact that using AR interfaces could improve the learning compared to more traditional tools as non-augmented environment and interactive tabletops based on multi-touch screen. These interfaces are robust but expensive and/or do not allow object surface augmentation.

The second one is directly questioning the generalization learning capabilities of such interfaces.

The latter question will probably not be answered during the three years of this PhD because of its deep complexity. Nonetheless, exploring how the brain learns during manipulation of documents whether on a WIMP or post-WIMP is crucial for designing hybrid environments that are fully dedicated to learning.

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